An Exercise in Spacecraft Mission Fractionation

Results for a Selected Mission Scenario
With
Derived Rules of the Road for Optimized Fractionation

(Final)

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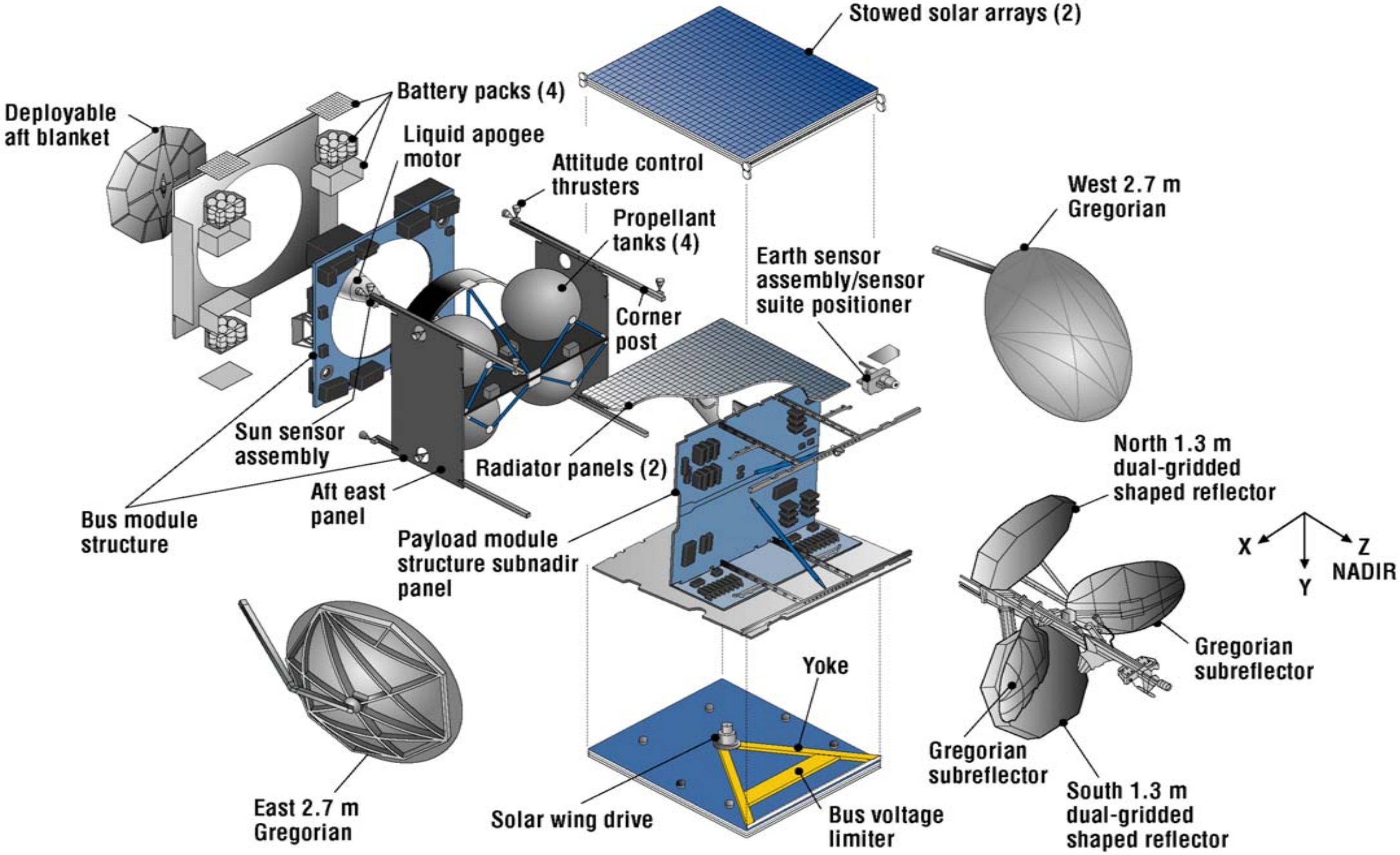
The Case for Fractionated Minisats:

- **Re-statement of the logic behind F6, and our evaluation approach :**
- **A Problem to Solve:**
  - In times when large multi-functional monolithic satellite programs are showing indications of over-complexity, extended schedules before inauguration, underestimated funding demands, it is appropriate to re-consider the application of segmented functionality using minisats
- **Potential Advantages:**
  - Reduced elemental launch costs with novel low-cost launchers
  - Opportunity for rapid response with minimally complex “building block” satellites
  - Early implementation of critical mission applications; time-staged funding
  - Enhanced mission and on-orbit robustness: launch vehicle failure tolerance; lowered mission recovery costs; graceful degradation
  - Mission enhancement/extension potential with later added features
- In 2005, Boeing undertook an internal **evaluation of mission segmentation**, based on stimulation by DARPA (Owen Brown) to consider the “F6” concept:
  - Exercised preliminary fractionation methodology with a known-state for evaluation: a Boeing 601HP Geostationary communications satellite
  - Several interesting initial conclusions were drawn, which resulted in the derivation of a set of guiding rules-of-the-road for efficiently applying segmentation

Fractionation Example: Boeing 601

- Evaluate fractionation of a known spacecraft
  - Allows reality-based focus on specific engineering
- Boeing 601 capable of broad range of missions
  - Primarily a GEO communications satellite
  - Typically 2500 kg BOL; 8 kW EOL; ~48 Transponders
- A fractionation strawman targeted lowest risk and maximized segmentation efficiency
- Spacecraft subsystems are physically interacting and inter-dependent, for both Monolithic and Fractionated:
  - Communications Payload
  - Housekeeping telemetry and command
  - Power (generation, storage, distribution)
  - Attitude and Orbit control
  - Propulsion
  - Thermal control
  - Structure
  - Launch vehicle interface
- Spacecraft can be segmented in several ways:
  - Maximized homogeneity vs. Functional Split

Boeing 601 Expanded View



601_010_021029.ppt_rev_04/01/02

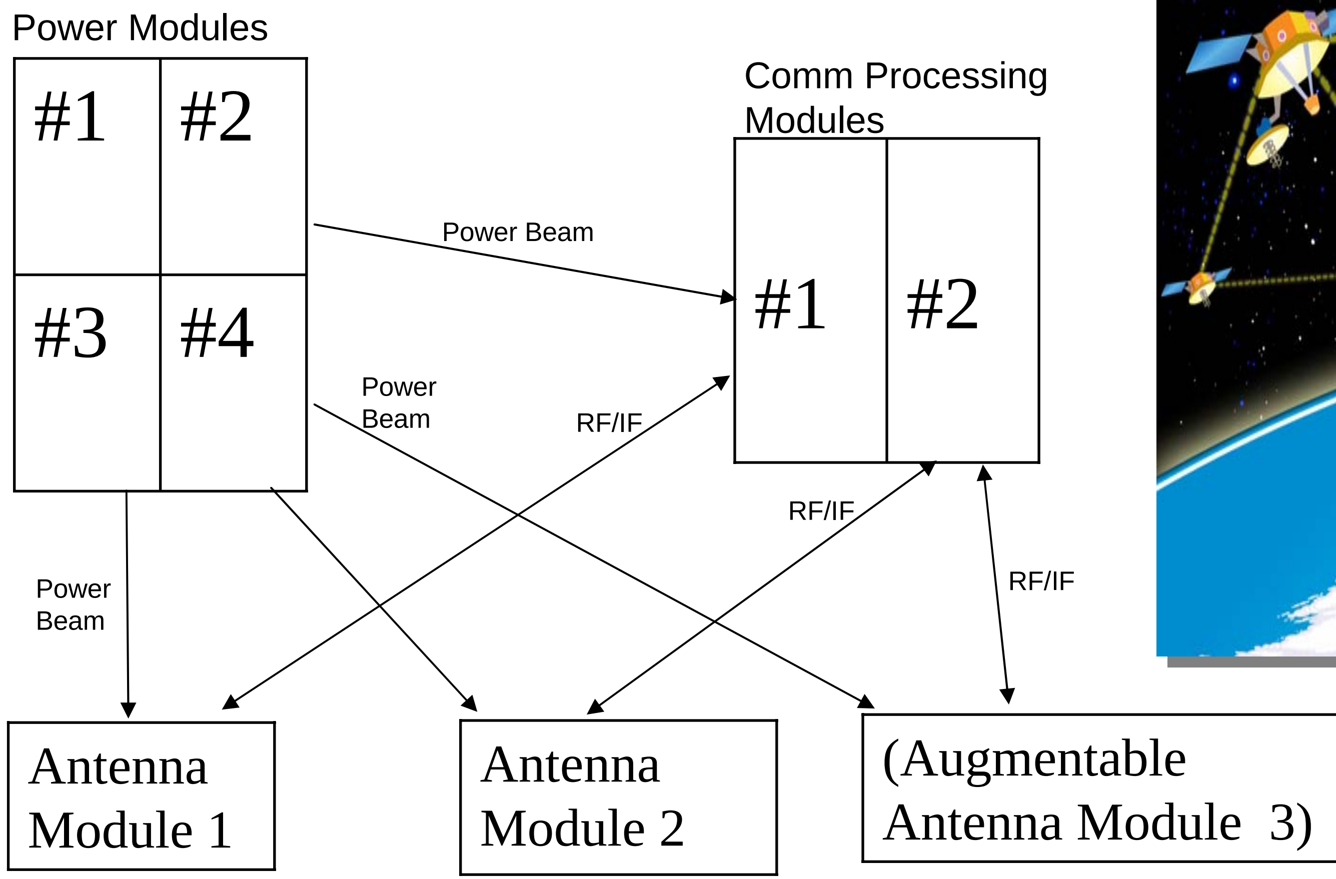
Methodology for Fractionation of 601 GEO ComSat

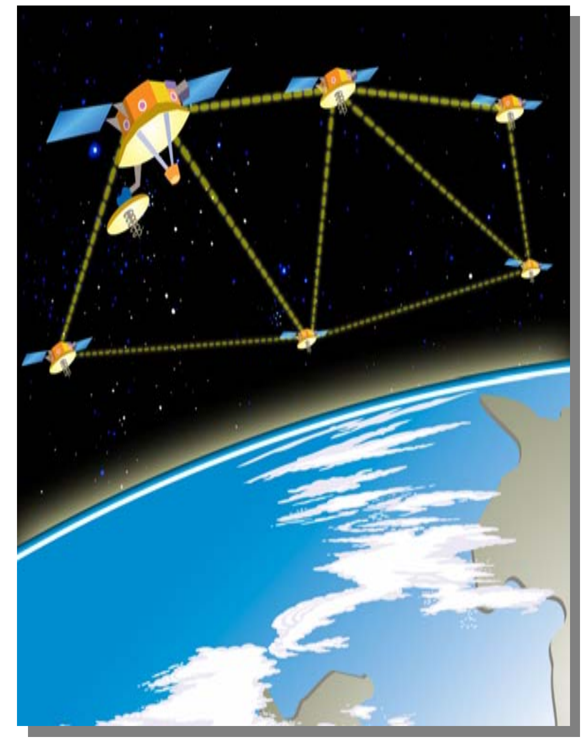
- Evaluate subsystem functionality and interactions
- Determine segmentation for mission-specific functional items that can be fractionated to satisfy the mission non-duplicatively (e.g. amplifiers)
  - Divide these elements into appropriately-sized fractionated blocks
- Determine segmentation for mission-support common-function items that are required in each node (e.g. structure; harness)
  - Divide up, where appropriate, common functional elements and distribute across multiple nodes
  - Duplicate as necessary those functions necessary to enable each node
- From the known monolithic spacecraft mass budget, examine detailed mass properties budget for each element within the nodes (unit level and above)
  - Determine the resultant node masses
- Iterative Optimization process:
  - Adjust node size/mass for maximized reuse of common elements
  - Target to achieve minimum number of nodes to satisfy functional division
  - Ensure each function duplicated at least once for robustness
  - Measure/adjust against most cost-effective launch vehicle solutions
- Resulted in preliminary evaluation only; more work needed to complete trades

Results of 601 Fractionation Exercise

- **Launch Restriction Penalty:** Choice to restrict for Falcon LV (≦1000 lb), or Optimize using derived Design Rules
- **Resultant mass penalty of +104%*** for fractionation of a selected Boeing 601 GEO communications mission for **Falcon** launch **(12 Nodes)**
  - Monolithic 601 BOL mass reference 2581 kg
  - 12 Node Falcon Fractionation BOL mass est. 5271 kg
    - 5 Power nodes, 3 Processing nodes, 4 HPA/Antenna nodes
- **Applying Design Rules** as derived (Fractionation without Launch Vehicle limitations), **mass penalty reduces to +68%** **(8 Nodes)**
  - 8 Node Optimized Fractionation mass est. 4344 kg
    - 4 Power nodes, 2 Processing nodes, 2 HPA/Antenna nodes
  - Module masses up to 1300 lb
- **Note: Preliminary Analysis only*
  - *Assumes 100% efficiency for power transport between modules. Mass penalty for Falcon-limited case increases to >250% if laser power conversion and distribution inefficiencies are included, due to increase in number of necessary power modules.*
  - *Calculation does not include any fuel necessary for attainment of final orbit, to permit unbiased evaluation of various orbit/mission possibilities, and avoid pre-judgement of methods for final orbit attainment (e.g. common-launch node deployment; time-sequenced launches etc.)*

Resultant Fractionation Diagram





Conclusions (1)

- **EFFECTIVITY**:
  - Resultant efficiency in fractionation is very dependent on the **class/type of mission** assumed: e.g. Geo communications missions are not appropriate from a cost standpoint; LEO geolocation may be an appropriate service, but single-cluster operations provides insufficient resolution
- **METRICS**:
  - Need to be very clear on the derived **Figures of Merit** for evaluating the cost/benefit **effectivity** of fractionation (e.g. robustness enhancement; mission enablement; early introduction; mission extension/augmentation; total life cycle costs; mass penalty)
  - Evaluations should be made clear and quantifiable;
  - Minor assumption/mission changes can radically change the "score"
- **TRADESPACE**:
  - Optimization of centralized vs. distributed functionality
- **COST**:
  - We determined that the initial optimism of possibly cheaper life-cycle costs was **not justifiable for this mission type,** as the system overhead and necessary service function duplication outweighed economies of cheaper smaller launch vehicles
- **ENGINEERING**:
  - Several **enabling technologies** would need development in order to capitalize on the opportunity and maximize operational efficiency:
  - Formation flying metrology and control
  - Power beaming; etc.

Conclusions (2)

- **LOGIC**:
  - Apply logical initial fragmentation into major sub-function blocks (e.g. power source/storage; processing; communications transmitters)
  - Minimize the **types** of blocks to those critical functional elements
- **INTERFACES**:
  - Minimize the **types of interface** between blocks (e.g. power interface only; not communications RF, plus power, plus T&C, plus OCS)
- **LAUNCH**:
  - Launch vehicle limitations artificially increase the number of modules, with inefficient duplication of housekeeping functions
  - Optimize functionality fractionation first, then evaluate the capability of various launch vehicles to find the lowest number of highest mass launches
- **COMMUNICATIONS:**
  - Keep the HPA to antenna interface physically intact
- **REDUNDANCY**:
  - Have at least two shared-capacity modules of each type, to accommodate robustness paradigm while avoiding multiple internal redundancies
- **MASS**:
  - Equalize the mass of each module:
    - Accomplishes synergy in design with max use of common building blocks; permits maximized advantage to be taken of learning curve and launch-vehicle bulk-buy economies